Shoulder proprioception in baseball pitchers

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We examined proprioceptive differences between the dominant and nondominant shoulders of 21 collegiate baseball pitchers without a history of shoulder instability or surgery. A proprioceptive testing device was used to measure kinesthesia and joint position sense. Joint position sense was significantly (P = .05) more accurate in the nondominant shoulder than in the dominant shoulder when starting at 75% of maximal external rotation and moving into internal rotation. There were no significant differences for proprioception in the other measured positions or with kinesthesia testing. Six pitchers with recent shoulder pain had a significant (P = .04) kinesthetic deficit in the symptomatic dominant shoulder compared with the asymptomatic shoulder, as measured in neutral rotation moving into internal rotation. The net effect of training, exercise-induced laxity, and increased external rotation in baseball pitchers does not affect proprioception, although shoulder pain, possibly due to rotator cuff inflammation or tendinitis, is associated with reduced kinesthetic sensation. (J Shoulder Elbow Surg 2001;10:438-44.)

INTRODUCTION

Throwing athletes have been shown to have several morphologic changes in their dominant extremities. Among the differences between dominant and nondominant arms, muscle hypertrophy and increased strength, increased bone density of the humerus, increased arm size, and increased shoulder external rotation have been identified. In addition, Pappas et al[13] noted loss of internal rotation in throwing athletes as a result of posterior capsular scarring. This presumably results from repeated injury, because there is an increased rate of injury to the rotator cuff (tendinitis and tears) in throwing athletes compared with age-matched counterparts who are not involved in overhead activities.[15] Recently it has been noted that throwing athletes also have increased laxity of the dominant glenohumeral joint, which results in symptomatic shoulder subluxation.[9] It has been hypothesized that this microinstability results in increased strain on the rotator cuff, which results in increased musculotendinous unit failure, clinically manifested as rotator cuff inflammation or injury (partial or complete tear) or as posterior glenohumeral impingement.[9,18] Although throwing athletes have increased external rotation of the dominant shoulder compared with that of the nondominant shoulder, their overall rotational arc (external rotation to internal rotation) is nearly the same between the two shoulders.[4,9,11,13] The etiology of this rotational difference remains controversial, although some investigators feel the increased external rotation of the dominant shoulder is the result of cumulative microtrauma causing plastic deformation of the capsule and ligaments.

Proprioception is a specialized variation of the sensory modality of touch and encompasses the sensations of joint movement (kinesthesia) and joint position (joint position sense). Conscious proprioception is essential for proper joint function in sports, activities of daily living, and occupational tasks. Unconscious proprioception modulates muscle function and initiates reflex stabilization. Recent work suggests that muscle and joint receptors are complementary components of an intricate afferent system in which each receptor modifies the function of the other. Articular and muscle receptors have well-established cortical connections that substantiate a central role.

Proprioceptive mechanoreceptors have been identified in the glenoid labrum and glenohumeral ligaments, suggesting that shoulder capsuloligamentous structures possess the anatomical basis for perceiving joint position and motion.[3,17] Clinically, the relationship of injury and disease conditions with proprioception and the effects of impaired proprioception on function have been studied in other joints; however, few studies have measured proprioception at the shoulder joint.[2,7,12,14] Tibone et al[16] have confirmed that these mechanoreceptors do provide afferent signals to the brain by showing the somatosensory-evoked potential response to electrical stimulation of capsuloligamentous

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structures of the shoulder during arthroscopy. Jerosch et al[8] have shown that mechanoreceptors do have a clinically detectable function in shoulder stability. Most research studies suggest that proprioception in the shoulder is based on capsular tension and is not related to hand dominance.[2,5,12,14] It has been shown that trained knee joints have better proprioception, but this has not been studied in trained shoulders.[1]

Because the shoulder is the most mobile joint in the body, it requires a complex interplay between static and dynamic factors in order to maintain stability throughout all arcs of motion. Dynamic stability is afforded by the coordinated contractions of the muscles acting across the shoulder joint. Joint compression and steering effect of the muscles provide motion and stability over the entire range of motion, and the ligaments and capsule statically limit excessive translations and rotations of the joint end ranges. We have previously hypothesized that proprioceptive feedback from capsular stretch mediates control of stability of this joint. We believe that microtrauma to the capsule and ligaments of the shoulder produces an alteration or disruption (or both) of the afferent feedback loop, which may produce subtle degrees of instability.

As previously noted, high-level baseball pitchers have inherent glenohumeral laxity, and laxity has been shown to result in reduced proprioceptive capabilities. However, the action of pitching a baseball, especially at high levels, requires the pitchers to repeatedly subject their shoulders to repetitive, forceful circumduction motions, resulting in neuromuscular training. Neuromuscular training has been shown to result in enhanced proprioceptive testing. Therefore we chose to study the proprioceptive function of baseball pitchers' shoulders—specifically, shoulder joint kinesthesia and position sense—to determine the net proprioceptive effect of repetitive high-level throwing in these unilateral arm–dominant athletes. Thus the goal of this study was to determine the net effect of training and recurrent microtrauma to the shoulder on proprioception of the glenohumeral joint.

MATERIALS AND METHODS

We studied 21 high-level collegiate baseball pitchers (mean age, 19.8 years [range, 18-22 years]) who had pitched for a mean of 10.5 years (range, 6-14 years) (mean, 2.5 years of college baseball). These pitchers comprised the top 4 to 6 pitchers (all with a fastball pitch >79 mph) of 4 college teams. Three pitchers had a history of shoulder dislocations and were excluded from the study. Exclusion criteria included a history of shoulder dislocation, other shoulder injury, or shoulder surgery. No pitcher had pitched for 1 day prior to testing. A detailed pitching, shoulder pain, and injury history was obtained by the same examiner. Physical examination consisted of a thorough evaluation of both shoulders assessing range of motion, irritability, and laxity. Specifically, range of motion was assessed by goniometric measurement of shoulder forward elevation, abduction, and internal and external rotation in 90° of abduction while the patient was in the supine position. Internal rotation and external rotation in adduction were measured with the patient standing. Irritability was defined as the presence of subacromial tenderness, a positive Neer impingement sign, a positive Hawkins impingement sign, or pain with resisted supraspinatus test.[10] Generalized ligamentous laxity was examined and noted to be increased by the presence of two of the following: positive thumb-forearm sign, recurvatum of either elbow (without previous injury to elbow), or hyperextension of metacarpophalangeal joints. Shoulder laxity assessment included the load and shift test, apprehension-relocation test, and sulcus sign. This examination was performed on all athletes by the same orthopaedic surgeon to eliminate the interindividual variation associated with nonquantifiable findings, such as anterior/posterior luxation.

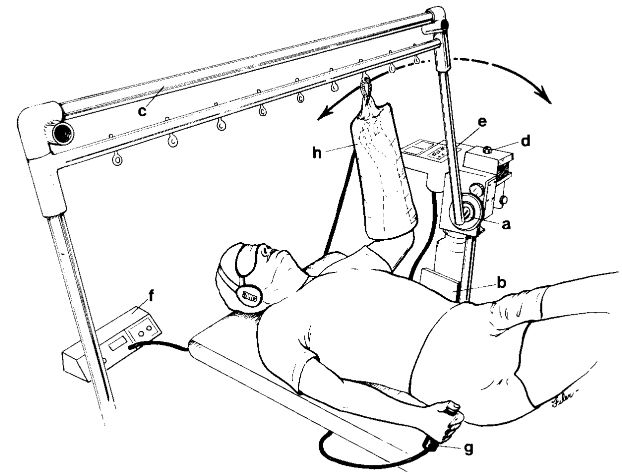

Figure Illustration of the proprioception testing device used for shoulder proprioception. The subject is in the supine position and is blindfolded, and the shoulder and elbow to be tested are in 90° of abduction and flexion, respectively. *a,* Rotational transducer; *b,* motor; *c,* moving arm; *d,* control panel; *e,* digital microprocessor; *f,* pneumatic compression device; *g,* handheld disengage switch; *h,* pneumatic compression sleeve. Kinesthesia as tested by TTDPM is assessed by measuring angular displacement until the subject senses shoulder motion. Joint position sense is assessed by the subject's ability to passively reproduce the angle of shoulder rotation that has been passively presented by the investigator.

A proprioceptive testing device (PTD) was used to measure kinesthesia as the threshold to detection of passive movement (TTDPM) and to measure joint position sense by the ability to reproduce passively joint positioning (RPP) (Figure). This device has been used previously to assess proprioceptive awareness.[12] The PTD rotates the shoulder into internal and external rotation through the axis of the joint. A rotational transducer interfaced with a digital microprocessor counter provided the angular displacement values directly. Subjects were tested in the supine position, as in previous studies.[7,12,14] The PTD rotates the arm at 0.5° per second. This speed was selected because it is slow enough to minimize contribution from muscle receptors. The arm of the tested shoulder was positioned at 90° of elbow flexion and 90° of shoulder abduction. The subject's forearm was placed in a pneumatic sleeve to reduce cutaneous input. The pneumatic sleeve was attached to the drive shaft of the PTD. To eliminate the proprioceptive effects of muscular fatigue,[5] no pitcher pitched for at least 1 day prior to testing.

The shoulder was tested from 3 starting positions into internal and external rotation. These positions were neutral rotation, 75° of external rotation, and the angle determined to be 75% of the maximal external rotation of each shoulder tested. The neutral rotation starting point was believed to be the resting position of the shoulder where anterior and posterior capsuloligamentous structures would be relaxed. Seventy-five degrees of external rotation was chosen as the angle at which tension on the capsuloligamentous complex should begin to play a role and some difference in afferent input might be demonstrated.[19] Seventy-five percent of maximal external rotation of each individual shoulder was used in an attempt to equalize the tension on the capsuloligamentous structures of the glenohumeral joint while taking into account the variation in maximal external rotation between the dominant and nondominant shoulders of these unilateral arm–dominant athletes.

Two familiarity trial tests were performed before the subjects were blindfolded and had headsets placed over the ears to negate visual and auditory cues. Testing was performed in a single session with the test order of dominant and nondominant shoulder, starting position, and direction of movement being randomized and counterbalanced. The PTD tester was blinded to the subject's dominant and nondominant arm. Instrument reliability has been previously established.[12] Intraclass correlations were calculated with the use of a fixed model and ranged from 0.87 to 0.92.

TTDPM assessment was started with the motor and shaft of the PTD disengaged. The subject was blindfolded and had earphones placed over the ears. The subject gave a thumb-up signal to indicate readiness to perform the test. At a random point during the subsequent 20 seconds, shoulder movement was engaged. The subject disengaged the PTD by pressing a handheld switch upon perception of sensation of movement at the shoulder. The PTD rotated the shoulder at a constant angular velocity of 0.5° per second. Three trials were performed from the starting positions of neutral rotation, 75° of external rotation, and 75% of maximal external rotation moving into both internal and external rotation. Both the dominant and nondominant shoulders were tested. Mean TTDPM values were calculated for the 6 test conditions.

For RPP testing, the subject was blindfolded but was permitted to communicate with the PTD tester during testing. Neutral rotation and 75% of maximal external rotation were used as starting positions (reference angle). After confirmation of the subject's readiness, the shoulder was moved passively 10° into external or internal rotation (presented angle). The angles were presented at variable velocities to reduce any time-associated cues. The velocities were varied during the individual positioning of the shoulder each time. The limb was held in the presented angle position for 10 seconds, and the subject was asked to concentrate on this position. The limb was then returned passively to the reference angle. The subject was then instructed to manipulate the on/off switch to reproduce the previously presented angle at an angular velocity of 0.5° per second. This was recorded and repeated for each of the starting positions moving into internal and external rotation. The difference between the presented angle and the angle that was repositioned by the subject was calculated as the error of reproduction. The mean of 3 trials was calculated for the 4 test conditions.

Dominant versus nondominant shoulder mean differences were analyzed with a paired *t* test for both TTDPM and RPP testing. Pearson product moment correlation coefficients were established between all dependent variables.

RESULTS

Eighteen collegiate baseball pitchers met the criteria for inclusion in the study group. They had a mean (± SD) age of 19.6 ± 1.4 years (range, 18-22 years) and pitched competitively for a mean of 10.3 ± 2.2 years (range, 6-14 years) (2.4 years of college baseball). Upper classmen (juniors and seniors) pitched for a mean of 11.3 years, and lower classmen pitched for a mean of 9.8 years. There were 14 right-handed pitchers and 4 left-handed pitchers. These pitchers used a mean of 3.2 different pitches in game situations. The mean speed of their fastball pitches was 83 ± 2 mph (range, 79-88 mph). Six pitchers threw predominantly overhand, 11 threw 3/4 arm, and 1 threw "short arm–3/4 arm." Eleven pitchers had a history of pain (remote or recent) around the shoulder that was significant enough to prevent them from throwing or pitching in a game or practice. Of these, 6 had a recent history of pain severe enough to prevent them from throwing.

The mean range of motion in 90° of abduction in the dominant arm was 38° ± 12° in internal rotation and 148° ± 11° in external rotation, whereas the nondominant arm had 51° ± 10° of internal rotation and 128° ± 9° of external rotation. All pitchers had greater external rotation in 90° of abduction in the dominant shoulder than in the nondominant shoulder (mean difference, 20° ± 5°; $P < .05$), but not with their arms at their sides (mean difference, 7° ± 6°). All pitchers had greater internal rotation in the nondominant shoulder with their shoulders abducted to 90° (mean, 13° ± 8°), although this difference did not reach statistical significance. The sum of each shoulder's internal rotation and external rotation in 90° of abduction (total arc) was not statistically different for each pitcher (mean, 186° ± 13° for the dominant shoulder and 179° ± 12° for the nondominant shoulder; mean side-to-side difference, 7° ± 10°). Upper classmen had a mean of 152° of external rotation in the dominant extremity, whereas the lower classmen had a mean of 142° in that shoulder.

Eight pitchers (44%) had increased generalized ligamentous laxity. Thirteen (72%) had no clinically detectable increased laxity of the shoulder, and the remaining 5 (28%) had increased anteroposterior glenohumeral laxity, as measured during the load and shift test.

Overall, there was no significant difference ($P < .05$) between the dominant and nondominant arms in pro-

Table I Comparison of proprioceptive testing in dominant and nondominant arms

	Dominant arm	Nondominant arm	*P* value
TTDPM			
NR → IR	2.35 ± 1.75	1.97 ± 1.13	.40
NR → ER	1.77 ± 0.98	1.81 ± 0.97	.89
75% ER → IR	1.71 ± 1.21	1.45 ± 0.84	.44
75% ER → ER	1.35 ± 0.70	1.35 ± 0.95	.96
75° ER → IR	2.21 ± 1.62	1.28 ± 0.49	.18
75° ER → ER	1.56 ± 0.88	1.26 ± 0.85	.32
RRP			
NR → IR	2.30 ± 1.51	2.76 ± 1.72	.35
NR → ER	1.63 ± 1.49	1.66 ± 1.43	.96
75% ER → IR	2.76 ± 1.80	1.77 ± 1.36	.05
75% ER → ER	2.32 ± 1.96	2.21 ± 1.62	.84

NR, Neutral rotation; *ER,* external rotation; *IR,* internal rotation; *75% ER,* starting at 75% of maximal external rotation; *75° ER,* starting at 75° of external rotation.

prioceptive testing (TTDPM and RPP) (Table I). However, RPP was statistically more accurate in the nondominant arm than in the dominant arm when starting in external rotation and moving into internal rotation (*P* = .05), whereas there was no difference when moving into external rotation from this starting position. Further, there was a trend toward enhanced kinesthesia sense in the dominant shoulder when moving into external rotation, when the starting position was brought into more external rotation (neutral rotation to 75° of external rotation to 75% of maximal external rotation). In addition, the dominant shoulder had better overall kinesthesia sense moving into external rotation as compared with moving into internal rotation, when testing from similar starting positions.

TTDPM was identical in the dominant and nondominant shoulders moving into external rotation, when starting at 75% of maximal external rotation. TTDPM was best in the dominant shoulder at 75% of maximal external rotation. For the nondominant shoulder with less maximal external rotation, 75° of external rotation and 75% of maximal external rotation were similar degrees of external rotation (within 15°). With similar amounts of nondominant shoulder external rotation during testing, the sensitivity to detect passive motion was not statistically different.

TTDPM in neutral rotation moving into internal rotation in pitchers with a recent history of pain was significantly diminished compared with that in those without any shoulder symptoms (*P* = .04) (Table II).

DISCUSSION

The baseball pitchers in this study are all highly trained athletes who compete at high levels. The greater external rotation in the dominant shoulder of throwing athletes with the shoulder abducted to 90° is believed to be related to recurrent capsular microtrauma with resultant joint laxity.

Many factors have been shown to affect shoulder proprioception testing. Those controllable factors known to affect proprioception testing have been addressed in this study. Because shoulder dislocation has been shown to affect proprioception, it was used as a basis for participant exclusion for this study.[12,14] Age was not an issue because all pitchers were aged 18 to 22 years. Shoulder fatigue was minimized by ensuring 1 day of rest prior to testing.[5] Potential bias introduced by the investigator during proprioception testing was reduced by blinding the examiner to the arm dominance of the pitchers tested.

Our study confirmed increased external rotation of the dominant shoulder with the arm abducted, with compensatory reduction of internal rotation measured from the same position and a resultant net rotational arc in 90° of abduction not significantly different between the dominant and nondominant shoulders.[9,13] The source of this shoulder rotation finding has not been definitively identified. The theory that soft tissue microtrauma was the cause of this rotation difference would appear to be supported by the fact that the upper classmen had greater external rotation than the lower classmen, although this requires more study to be definitively confirmed. The microtrauma theory suggests that throwing athletes may develop excessive external rotation in abduction as a result of repetitive stress to the anterior-inferior capsule during the throwing motion. Further, the high forces during the follow-through phase of throwing may cause scarring and shortening of the posterior capsule and rotator cuff muscles, resulting in the reduced internal rotation in abduction. This microtrauma theory has recently been reported in tennis players: older players with more years of play had a greater increase in external rotation in 90° of abduction in the dominant shoulder than in the nondominant shoulder and a corresponding decrease in internal rotation in abduction in the dominant shoulder.[11] Rotation was not statistically different with the arms at the sides.

This study also shows that asymptomatic baseball pitchers, whose dominant shoulders have increased

Table II Proprioceptive testing in dominant and nondominant arms with or without recent tendinitis

	Dominant	Nondominant
Tendinitis		
TTDPM		
NR → IR	1.74 ± 0.97	2.70 ± 1.40
NR → ER	1.73 ± 1.06	2.09 ± 1.14
75% ER → IE	1.20 ± 0.31	1.66 ± 1.05
75% ER → ER	1.21 ± 0.52	1.54 ± 0.92
RPP		
NR → IR	2.44 ± 1.57	2.29 ± 0.79
NR → ER	1.29 ± 1.56	1.63 ± 1.87
75% ER → IR	2.11 ± 1.56	0.94 ± 0.55
75% ER → ER	2.59 ± 2.33	2.46 ± 1.73
No tendinitis		
TTDPM		
NR → IR	2.73 ± 2.05	1.65 ± 0.76
NR → ER	1.83 ± 1.10	1.67 ± 0.93
75% ER → IR	2.03 ± 1.41	1.43 ± 0.78
75% ER → ER	1.57 ± 0.83	1.39 ± 1.07
RPP		
NR → IR	1.77 ± 0.85	3.10 ± 2.24
NR → ER	1.92 ± 1.51	1.68 ± 1.30
75% ER → IR	3.01 ± 1.81	2.41 ± 1.64
75% ER → ER	2.67 ± 1.78	2.21 ± 1.76

NR, Neutral rotation; *ER,* external rotation; *IR,* internal rotation; *75% ER,* starting at 75% of maximal external rotation.

external rotation in 90° of abduction, have similar proprioceptive sensation in the dominant and contralateral shoulders. The only statistically significant difference in proprioception testing was that joint position sense was reduced in 75% of maximal external rotation moving into internal rotation in the dominant shoulder. Because the total arc of motion is similar in the dominant and nondominant shoulders, testing at 75% of maximal external rotation should result in similar shoulder capsular tension, and thus proprioception based solely on capsular tension should be the same. This statistical difference might be explained by one of several mechanisms that are beyond the scope of this study: (1) the benefit of training the dominant extremity, (2) passive tension within the muscle and the receptors within the musculotendinous unit, and (3) the effect of glenohumeral translation during testing affecting receptor output.

The ability to detect passive motion (TTDPM) did not differ between the dominant and nondominant shoulders moving into external rotation when starting at 75% of maximal external rotation, where the capsular tightness should be similar. There was a trend for improving TTDPM sensitivity in the dominant shoulder moving into external rotation as the starting angle is increased from neutral rotation to increasing degrees of external rotation. TTDPM was best in the dominant shoulder at 75% of maximal external rotation, where the anterior capsule is under greatest tension. However, for the nondominant shoulder, 75% of maximal external rotation was often not the greatest degree of external rotation tested (75° was often the maximal degree of external rotation used as a starting point for testing in the nondominant shoulder). Thus 75° of external rotation as the starting angle resulted in more capsular tension in the nondominant shoulder, which may explain the better results for TTDPM at this starting angle in the nondominant shoulder, as compared with 75% of maximal external rotation. Further, with the starting angle at 75° of external rotation, TTDPM was worse (although not statistically significant) in the dominant shoulder than in the nondominant shoulder moving into external rotation. This may be expected as well, because anterior capsular tightness in 75° of external rotation would be less in the dominant shoulder (because of its greater ability to externally rotate).

There was no statistically significant difference in TTDPM moving into internal rotation from a starting angle of 75° of external rotation. However, a trend of enhanced proprioception of the nondominant shoulder starting at 75° of external rotation and moving into internal rotation for TTDPM compared with that of the dominant shoulder is suggested. This lack of statistical significance may be due to the large standard deviation. A potential explanation of this trend may be the fact that the nondominant shoulder is likely starting with more anterior capsular tension and thus is more sensitive to change (decreasing tension and receptor output in this case) as it is moved into internal rotation. These findings support a capsular mechanism for shoulder proprioception in baseball pitchers; there is a greater response of capsular mechanoreceptors to tension in the glenohumeral ligaments at the end range of rotation, as has been shown with the neurologic properties of joint receptors.[6]

The 6 pitchers in this study with a recent history of shoulder pain thought to be due to rotator cuff inflammation or tendinitis had a significant deficit in their proprioception compared with that in their contralateral, nondominant shoulders. This may be due to ongoing tendinous or capsular injury or the effect of nociceptors. Whether the reduced proprioception caused the shoulder pain and/or rotator cuff inflammation or tendinitis or resulted from the pain, inflammation, or tendinitis is not known. Theoretically, this proprioception deficit might further lead to an uncoordinated muscle firing and recruitment pattern that could exacerbate rotator cuff overload. Warner et al[20] have shown that individuals with instability and impingement have altered scapulothoracic motion, as determined by Moiré analysis. This alteration in motion may be the result of an uncoordinated muscle firing pattern due to a proprioceptive deficit. This supports our paradigm explaining the relationship between proprioception and shoulder instability, which includes attenuation of the glenohumeral capsule and ligaments over the course of time during repetitive overhead activities.[12] We hypothesize that this microtrauma leads to degrees of instability that either damage peripheral afferent receptors found in the static structures of the shoulder joint or stretch the capsuloligamentous complex that reduces the stimulation of the mechanoreceptors. The resultant deficits in proprioceptive feedback due to the partial deafferentation of these receptors contribute to the insidious cycle of shoulder instability due to decreased reflex muscle stabilization. We believe that the instability and discoordinated muscular action may also be manifested as shoulder pain due to rotator cuff inflammation. The rotator cuff inflammation may be due to overuse or to impingement of the cuff between the humeral head and the acromion, as the dysfunctional rotator cuff cannot maintain the humeral head centered within the glenoid. We have previously postulated that cumulative microtrauma to the capsular structures in athletes during repetitive overhead motions may be a mechanism for disruption of the normal afferent feedback loop that helps stabilize the shoulder joint by reflex muscle contraction. This could be a mechanism for acquired shoulder subluxation in overhead athletes. Future electromyographic studies may aid in confirming this hypothesis, and proprioceptive enhancement or reeducation may play a role in the prevention of some overuse throwing injuries.

This study provides more evidence that suggests a capsular mechanism for shoulder proprioception. Pitching does cause alterations in range of motion, with increased external rotation of the dominant shoulder in 90° of abduction and reduced internal rotation in abduction. It is assumed that this reduced internal rotation in abduction of the dominant shoulder, as compared with that of the nondominant shoulder, is due to posterior capsular tightness. Similarly, the greater external rotation in abduction of the dominant shoulder is assumed to be due to less anterior capsular tightness in the dominant shoulder in abduction with similar degrees of external rotation. We note this has not been proved, and other potential causes, including scapular inclination, may also result in increased external rotation of the dominant shoulder. The alteration in capsular tension in different degrees of rotation, while the shoulder is abducted, may result in alterations in proprioception. However, with equal amounts of capsular tension (75% of maximal external rotation), there was no difference in kinesthesia or joint position sense between the dominant and nondominant shoulders of high-level baseball pitchers, with the exception of reduced joint position sense in external rotation moving into internal rotation. This finding at 75% of maximal external rotation suggests that the potential beneficial effects of repetitive throwing resulting in neuromuscular training may be offset by repetitive capsular injury from the microtrauma associated with the repetitive throwing mechanics of pitching.

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